DEFENSE RESEARCH LABORATORY

THE UNIVERSITY OF TEXAS
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A STANDARDIZED TRANSDUCER CALIBRATION SYSTEM FOR NAVAL SHIPYARD TRANSDUCER REPAIR FACILITIES

by

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ABSTRACT

The severe need for up-to-date underwater acoustic transducer calibration systems at the three Naval Shipyard Transducer Repair Facilities (Boston, Pearl Harbor, and San Francisco Bay) was reported to the Bureau of Ships in February 1965. Defense Research Laboratory was given the responsibility of designing on paper an optimum standardized transducer calibration facility. A meeting in the Bureau of Ships on 27 October 1965 used the general framework of the optimum system to generate a "master list" of instrumentation for the design of a standardized transducer calibration system for the Naval Shipyard Transducer Repair Facilities. The necessary testing capabilities required by the Repair Facilities were discussed and agreed upon. Defense Research Laboratory was asked to compile a final report based on the results of the meeting. This report describes in detail the necessary testing capabilities, the necessary instrumentation, and the general testing procedures. A detailed list of specifications for the system is presented. The system is designed for farfield measurements but is compatible with nearfield techniques. An itemized approximate price list is included for planning purposes. It is recommended that at least four "turn key" systems of the specified design be purchased for the shipyard transducer repair facilities. It is further recommended that all other related requirements of these facilities be improved to a point commensurate with the calibration system, and that work begin on outlining standardized testing procedures for the facilities.

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I. INTRODUCTION

This report describes in detail an underwater acoustic transducer calibration system tailored to the present and future needs of the three Naval Shipyard Transducer Repair Facilities--Boston, Pearl Harbor, and San Francisco Bay. The severe need for such an up-to-date system at these existing facilities was reported to BuShips in February 1965; the system described herein represents the culmination of one phase of a study initiated by the Bureau of Ships, Code 1622D, for the purpose of correcting this deficiency. It is emphasized that this report deals with only the calibration instrumentation. Other related needs at these facilities will be dealt with in the near future. Such needs as housing, adequate water conditions, and transducer handling and rotating capabilities will necessarily be custom engineered for each particular facility. Further study is necessary before standardized testing and calibration procedures can be outlined for the repair facilities. This will result in a greatly modernized counterpart of the existing Performance Standards Book for Sonar Transducers.

Section II presents the sequence of events that has led to the present report. The next section contains the system design parameters, a detailed description of the system and its components, and a general outline of testing procedures. A summary and recommendations conclude the report. A list of system component prices is included as Appendix A; the minutes of the BuShips committee meeting at which the system design was approved compose Appendix B.

II. BACKGROUND

Pursuant to recommendations made by the Underwater Sound Advisory Group, the Bureau of Ships, Code 1622D requested Defense Research Laboratory to conduct a study to determine present and future transducer calibration and testing requirements. This study was reported upon in February 1965.[1] One recommendation of this study was that steps be taken to improve the three transducer repair facilities which are located at Naval Shipyards--Boston, Pearl Harbor, and San Francisco Bay. These facilities were found to be lacking in up-to-date testing and calibration instrumentation, in adequate procedures, and in engineering assistance in general.

Defense Research Laboratory was given the responsibility of designing on paper an optimum standardized transducer calibration facility, with no particular installation in mind. The facility was to be designed for farfield acoustic measurements, but compatibility with nearfield techniques was to be maintained, if possible. The instrumentation was to consist of off-the-shelf items and was to be modular in design, if possible. The preliminary design, in the form of a "first draft" report,[2] was circulated to the proper government activities for comparison with existing facilities and for constructive criticism. The comments were analyzed and presented in a meeting at the Bureau of Ships on 27 October 1965. This meeting was expressly for the purpose of using the general framework of the optimum system to design a standardized instrumentation system for the three transducer repair facilities. This report presents the design agreed upon at the meeting. A copy of the minutes of the meeting is included as Appendix B.

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[1] D. D. Baker, G. R. Barnard, and J. E. Stockton, "The Transducer Calibration Requirements and Capabilities of The Bureau of Ships--Present and Future(U), DRL Acoustical Report DRL-A-238, 15 February 1965. (Confidential)

[2] D. D. Baker and J. E. Stockton, "Design of an Optimum Standardized Transducer Calibration Facility" (First Draft), 24 May 1965.

III. SYSTEM DESIGN

A. Necessary Testing Capabilities

In the original optimum facility design,[3] DRL was asked virtually to design a calibration system versatile enough to handle any underwater acoustic measurements that might be necessary on any present or future transducers. The knowledge gained from DRL's study of present calibration facilities[4] and DRL's general calibration experience were supplemented by the American Standard Procedures[5] in order to compile a list of measurement capabilities that would assure versatility. This list is as follows:

1. Real-time plotting of horizontal or vertical beam patterns--pulsed or continuous-wave (CW).
2. Real-time plotting of rotational directional transmission (RDT) beam patterns.
3. Real-time plotting of sensitivities vs frequency--pulsed or CW.
4. Real-time plotting of complex impedance or admittance vs frequency at full driving power--pulsed or CW.
5. Measurement of harmonic distortion--pulsed or CW (after the recent work of Bishop and Wilson[6]).

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[3] Ibid.

[4] Baker, Barnard and Stockton, op. cit.

[5] American Standard Procedures for Calibration of Electroacoustic Transducers, Particularly Those for use in Water Z-24.24-1957 (American Standards Association, New York, 1957).

[6] G. L. Bishop and L. C. Wilson, Jr., The Measurement of the Free-Field Total Harmonic Distortion as a Criterion of Underwater Transducer Performance Evaluation (U), U. S. Navy Underwater Sound Lab Report No. 636, 15 December 1964.

6. All present tests currently in use at Naval Shipyards (from the Performance Standards Book for Sonar Transducers).

7. (Optional) Semiautomated reciprocity or comparison measurements of sensitivity vs frequency.

The types of measurements outlined allow computation of such parameters as directivity index, efficiency, and mechanical Q. Item 3 allows conventional reciprocity measurements to be made with a minimum of data-reduction time. Item 6 was included to point out specifically that the design would not exclude any current shipyard test procedures.

Semiautomated reciprocity or comparison measurements, such as those pioneered by the U. S. Navy Electronics Laboratory[7] were considered to be an optional capability of the optimum facility. The additional instrumentation necessary for this feature is listed as Option A.

In the 27 October 1965 meeting, oriented strictly to the Naval Shipyard Facilities, the entire list of capabilities was approved as reasonable for the shipyards with the exception of item 2. The desirability of this capability was questioned. The majority of the group favored elementwise or stavewise checking of transducers. Such checks are straightforward and would be sufficient if proper tests and tolerances were devised, because the shipyards are intended to deal with production transducers of proved design. Because Boston makes RDT measurements already, item 2 was not deleted but was reduced to an optional status. This actually represents a philosophical decision that will be reflected in future work on standardized procedures. The result of this decision was the addition of two options to the power amplifier specifications.

[7] J. R. Roshon, Electroacoustical Transducer Calibration Combined with Semi-Automatic Data Reduction, Navy Electronics Lab Technical Memorandum No. TM469, 18 April 1961.

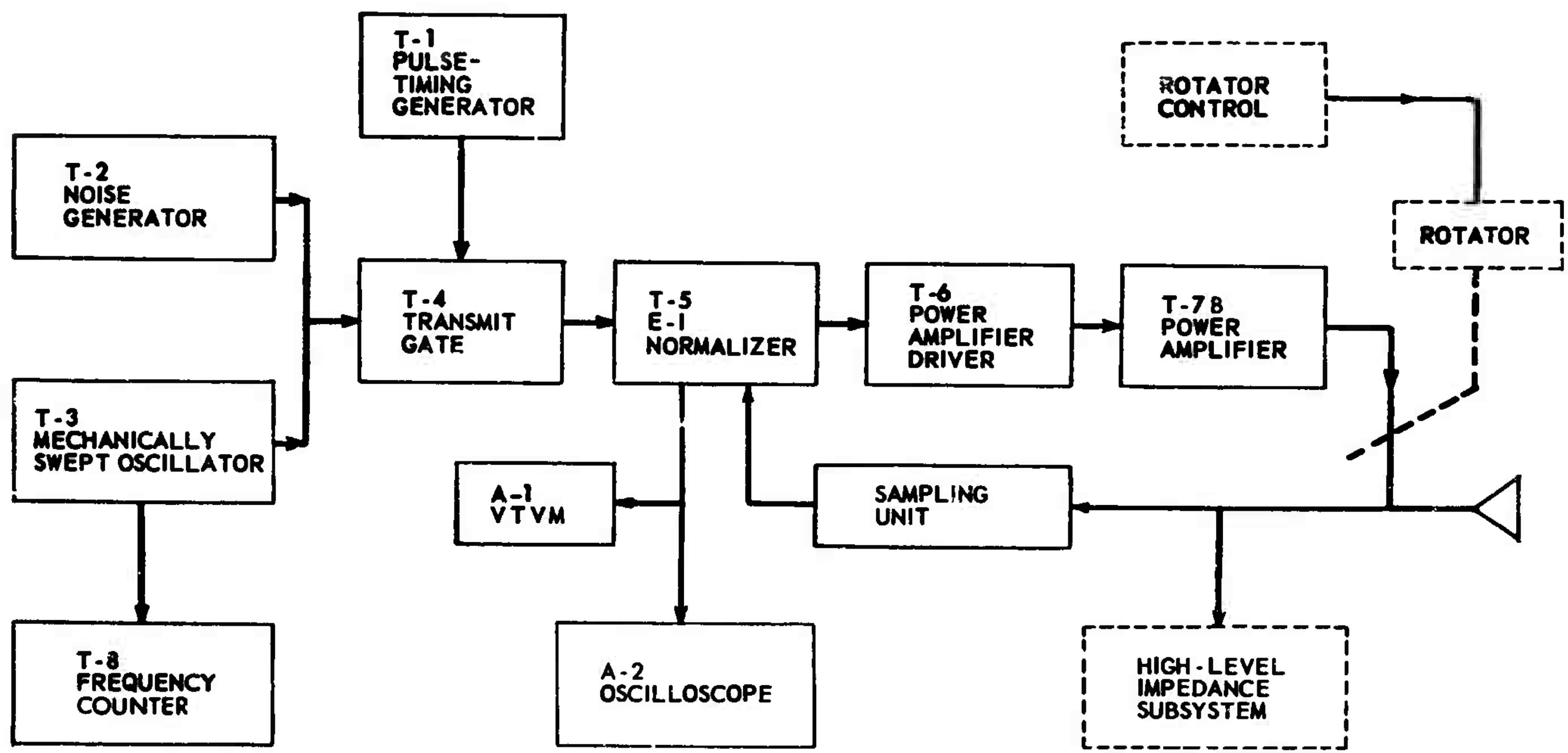

FIGURE 1
TRANSMITTING SUBSYSTEM

DRL - UT
DWG AS-65-1383
DDB - RGD
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The group questioned the shipyards' need for reciprocity measurement capability, but item 7 was still included (as an option) because of the semiautomated comparison measurement feature.

B. Necessary Instrumentation

All of the seven foregoing capabilities, with the exception of item 4, are readily attainable with current off-the-shelf instruments. Item 4 was originally included because of its great desirability and because developmental work on the necessary instruments appeared promising. Because these instruments are not presently available, this capability cannot be fully realized. Instruments are included capable of plotting low-level, CW impedance or admittance vs frequency. A high-level impedance subsystem is also included; it permits the use of two different techniques for measuring point-by-point impedance, pulsed or CW transmission. Instruments are available for plotting high-level, CW impedance or admittance vs frequency. These are not recommended for shipyards because of the normal pulsed operation of fleet transducers. It is likely that a full-power CW duty cycle would damage transducers or at best would give different impedance values from pulsed measurements. Also such instruments provide for only discrete current or voltage drive levels; therefore, measurements could not be made at the exact drive levels specified for fleet use. This defeats the main concept of high-level impedance measurements--a transducer performance check at the full power driving level.

A general description of units recommended for the system is presented. Many of these serve obvious functions and require no explanation. Functions of other units are stated briefly. Subsection C lists detailed specifications of all of the units. For easy identification, all transmitting components are given a number (T-), as are receiving and auxiliary components (R- and A- , respectively).

Figure 1 shows a block diagram of the transmitting subsystem. The pulse-timing generator triggers the transmit gate either repetitively or on external command. The gate generates variable-length pulses of the sinusoidal

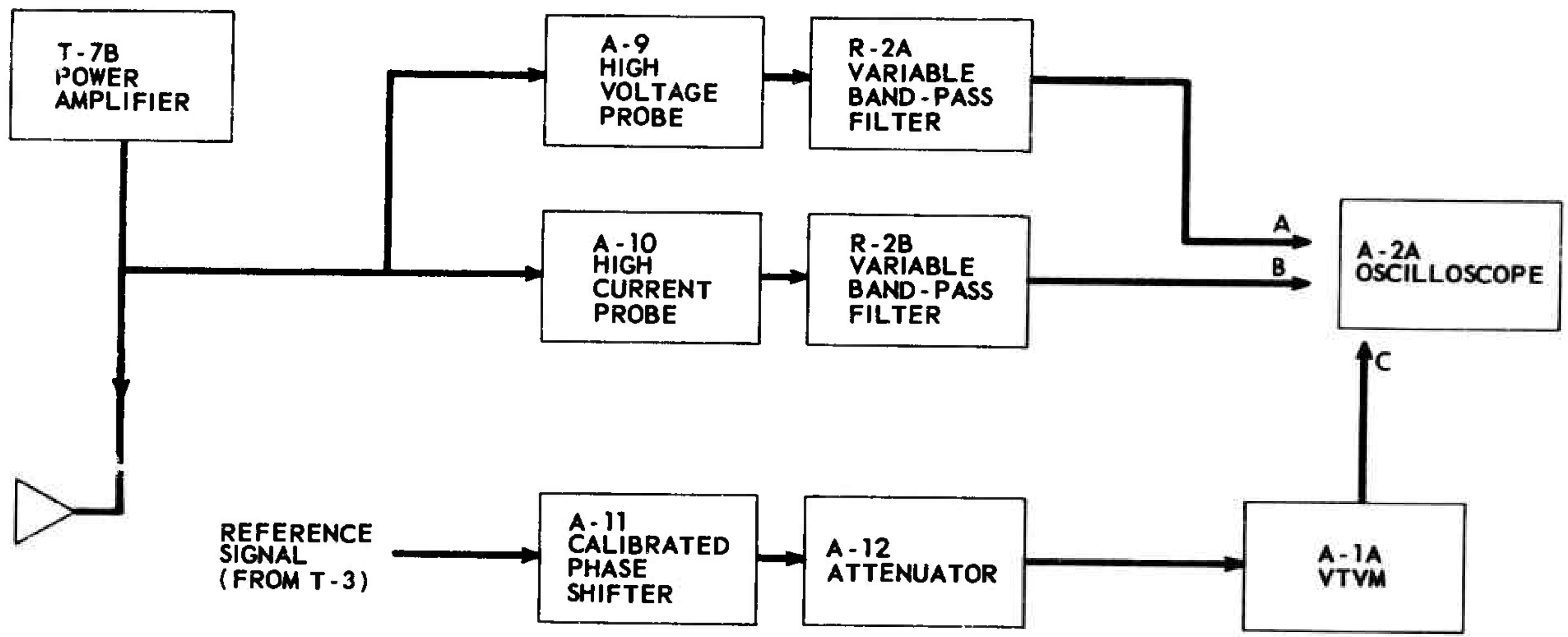

FIGURE 2
HIGH-LEVEL IMPEDANCE SUBSYSTEM

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signal from the mechanically swept oscillator, or of the noise from the noise generator. The transmit gate can be switched to the CW mode, which allows the input signal to pass through uninterrupted. The sampling unit (actually a part of the E-I normalizer) monitors transducer drive voltage or current in order to provide feedback to the E-I normalizer. This device is a variable gain amplifier that automatically holds constant the drive voltage or current, as frequency is changed. This feature is used for plotting frequency responses. The power amplifier driver is a variable gain amplifier that is adjusted to maintain sufficient drive voltage for the input of the power amplifiers.

Power amplifiers are specified that provide 24 kVA over the audio range and low power up to 500 kc/sec. The 24-kVA capacity is provided by eight 3-kVA modules. This modular feature gives great versatility in both output power and output impedance, as well as compatibility with the following two power amplifier options. The first option provides for 12 additional 3-kVA modules (a total of 20) to make possible RDT measurements on four of the present fleet transducers. The second option provides a total of 12 modules, the number required for stationary directional transmission (SDT) measurements with the same four transducers. For RDT or SDT measurements, the system transmit scanners must be provided and the modular amplifier is necessary because each stave must be driven with a separate amplifier.

The high-level impedance subsystem (shown in Figure 1) is block diagrammed in Figure 2. The filters R-2A and R-2B are used to pass only the fundamental of the transducer driving voltage or current. The attenuator (A-12) is used for fine adjustment of the reference signal as shifted in phase by A-11. The oscilloscope is used either for comparing inputs A and B or for comparing either A or B against the reference input C.

The receiving subsystem is depicted in Figure 3. The differential preamplifier (R-1) is a remote controlled unit which can be located above the water line near a transducer--thus eliminating long transducer test cables. The line driver is for the purpose of driving the 75-Ω input of the receive gate from the higher output impedance of the filter. The receive gate is triggered by the pulse-timing generator after an adjustable delay from the start of the transmit gate. A pulse detector plug-in unit, contained in each recorder (R-5 and R-6), generates a dc voltage proportional to the peak amplitude of the signal from the variable-length receive gate. At any instant, the detector output is proportional to the peak amplitude of the previous pulse that it received. There is no integration of the amplitudes of several pulses. In CW measurements, the receive gate is switched to the CW mode; the detector output is proportional to the instantaneous amplitude of the CW signal input. The detector drives the pen of the polar recorder (for polar directivity patterns) or the pen of the rectangular recorder (for rectangular directivity patterns or frequency responses). The chart drive signal to the rectangular recorder for frequency responses is provided by the frequency-tracking servo. This device (R-7) receives a signal proportional to frequency from the counter (T-8) and converts it to a chart position. For either type directivity pattern, the chart drive is provided by the synchro position output of the transducer rotator.

All functions described thus far in the three subsystems are either pulsed or CW.

Several auxiliary items are also specified as parts of the system. Among these are two wave analyzers that cover different portions of the frequency range. A mechanical sweep drive is included for sweeping a frequency range with the analyzers. A complex impedance-admittance meter is included for measuring low-power impedance or admittance (CW only). With this unit the real and imaginary components may be plotted vs frequency on a two-pen, X-Y recorder. This recorder may also be used to plot wave-analyzer output vs frequency.

An oscilloscope, ac voltmeter, calibrator, and step attenuator are included for general monitoring and system calibration purposes.

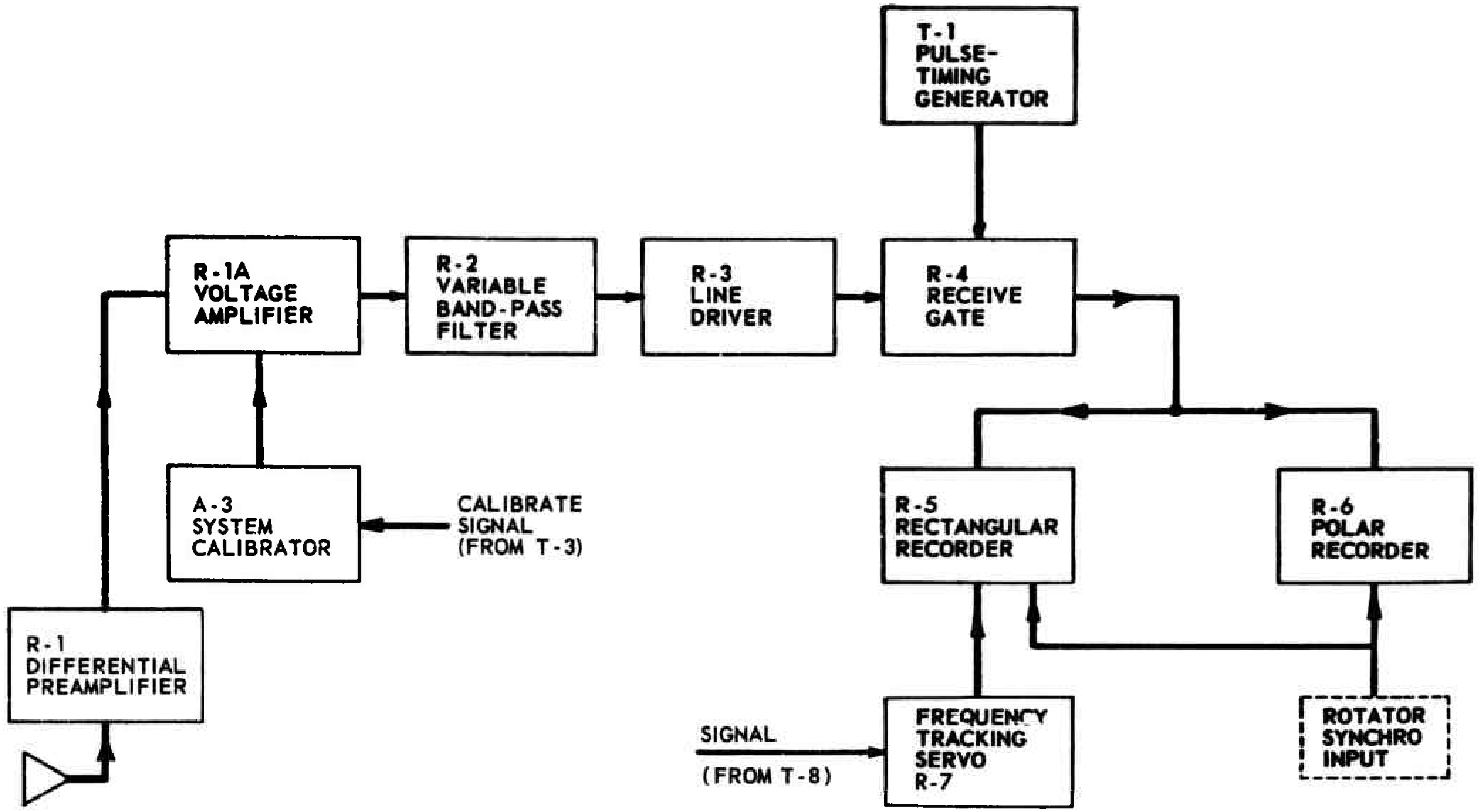

FIGURE 3
RECEIVING SUBSYSTEM

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Option A includes an X-Y recorder equipped with an optical line follower and a summing panel. This gives the capability of plotting the frequency response of one transducer, to which has been added algebraically the response of another transducer. This eliminates most data reduction from responses made by comparison measurements.

C. Instrument Specifications

1. General System

Operating Mode:	Pulsed or CW
Frequency Range:	50 cps to 500 kc
Dynamic Range:	50 dB
Pulse Repetition Frequency:	0.1 cps to 11 kc
Signal Gate Duration:	100 μsec to 11 sec
Linearity:	±0.5 dB over 50-dB Range
Data Presentation:	Logarithmic or Linear; Rectangular and Polar Coordinates
Impedance Measuring:	Low Power - 100 cps to 200 kc (CW only) 10Ω to 50kΩ High Power - 200 cps to 15 kc (Pulsed or CW)
Transmit Power:	24 kVA, 200 cps to 15 kc 50 W, 50 cps to 500 kc unbalanced 100 W, 50 cps to 500 kc balanced

2. Transmitting Subsystem

T-1: Scientific-Atlanta, Model 1118B, Pulse Timing Generator (Modified).

Pulse Repetition Frequency:	0.1 cps to 11 kc
Signal Gate Duration:	100 μsec to 11 sec
Duty Cycle:	95%

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T-2: Grason-Stadler, Model 455C, Noise Generator.

Operating Mode:	White Noise
Frequency Bands:	20 cps to 20 kc 20 cps to 100 kc
Optimum Output:	1 V into 600Ω
Gain:	Continuously variable between zero and full gain

T-3: Hewlett-Packard, Model 651A Oscillator.

Frequency Range:	10 cps to 10 Mc
Output:	3.16 V into 75Ω or 600Ω
Maximum Distortion:	less than 1% 10 cps to 5 Mc

T-4: Scientific-Atlanta, Model 1111, Transmitter Signal Gate.

Operating Mode:	Pulsed or CW
Frequency Range:	dc to 3 Mc
Input Voltage:	1 V rms
Linearity:	Less than 0.5-dB error over 50-dB range
Pulse Width and Repetition Rate:	Limited only by switching time of less than 1 μsec

T-5: Scientific-Atlanta, Model 1153, Voltage-Current Normalizer.

Operating Mode:	Pulsed or CW
Frequency Range:	50 cps to 2 Mc
Dynamic Range:	50 dB
Voltage Range:	0.1 V to 150 V
Current Range:	0.01 A to 15 A
(Voltage and current range can be increased if required.)	
Accuracy:	0.25 dB, 200 cps to 1 Mc 0.75 dB, 50 cps to 2 Mc
Drift Rate:	0.25 dB/pulse at 0.1 pps, less at higher pulse repetition frequencies

T-6: General Radio, Model 1206-B, Unit Amplifier.

Frequency Range:	2 cps to 500 kc
Output Voltage:	Nominally 10 V into 600Ω
Gain:	32.6 dB into 600Ω

T-7: Krohn-Hite, Model DCA-50, Power Amplifier.

Frequency Range:	dc to 500 kc
Maximum Voltage:	130 V rms
Maximum Current:	550 mA rms
Voltage Gain:	20 dB

T-7A: (Same as T-7)

T-7B: CML, Model A3K, Power Amplifier.

Frequency Range:	±2 dB, 200 cps to 15 kc
Rated Power:	3 kVA per module into zero power factor load
Number of Modules:	8 (12 optional, 20 optional)
Output Impedance:	4/16/32/64/144/576
Input Signal:	1 V rms into 600Ω

T-8: Hewlett-Packard, Model 5532A, Electronic Counter.

Frequency Range:	2 cps to 1.2 Mc

3. Receiving Subsystem

R-1: Scientific-Atlanta, Model 1116-1 Preamplifier.

This unit is currently under development.

Tentative specifications are:

Frequency Range:	50 cps to 2 Mc
Gain:	0-40 dB in 10-dB steps

(The gain is remotely controlled from a separate control panel)

Maximum Output Voltage:	1 V rms
Input Impedance:	1500 MΩ shunted by 20 pF
Input:	Differential

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R-1A: Scientific-Atlanta Model 1116-4 Preamplifier.

This unit is currently under development.

Tentative Specifications are:

Frequency Range:	50 cps to 2 Mc
Gain:	0-40 dB in 10-dB steps
Maximum Output Voltage:	10 V rms into 75Ω·
Input Impedance:	Designed to cascade with differential preamplifier
Input:	Single ended

R-2: Krohn-Hite, Model 312, Variable Electronic Filter.

Frequency Range:	Band-pass Mode - 20 cps to 200 kc High-pass Mode - Low Cutoff Variable from 20 cps to 200 kc Upper 3-dB Point 4 Mc
Rejection:	24 dB per octave per section
Output Impedance:	500Ω

R-2A, 2B: (Same as R-2)

R-3: Scientific-Atlanta, Model 1121, Line Driver.

Frequency Range:	50 cps to 2 Mc
Impedances:	Designed to match output impedance of filter to 75-Ω input impedance of receiver gate

R-4: Scientific-Atlanta, Model 1112, Receiver Signal Gate.

Operating Mode:	Pulsed or CW
Frequency Range:	dc to 3 Mc
Input Voltage:	1 V rms, normal full-scale signal
Input Impedance:	75Ω
Linearity:	Less than 0.5-dB error over 50-dB dynamic range
Pulse Width and Repetition Rate:	Limited only by switching time of less than 1 μsec

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4. Recording System

R-5: Scientific-Atlanta, Model 1162 - S136 Polar Pulse Recorder.

Operating Mode:	Pulsed, CW, or dc
Frequency Range:	50 cps to 2 Mc
Maximum Input Voltage:	1 V rms
Dynamic Range:	50 dB
Linearity:	±0.25 dB over 50-dB dynamic range
Pen Response:	Linear dc or logarithmic ac
Chart Response:	Synchro Speed Ratios of 36:1 or 1:1
Recording Format:	Polar, with 10 dB/inch scale factor
Pen Writing Speed:	50 in./sec

R-6: Scientific-Atlanta, Model 1163, Rectangular Pulse Recorder.

(Same as R-5 except for the following:)

Recording Format:	Rectangular, with 5 dB/inch scale factor
Pen Writing Speed:	Greater than 60 in./sec
Chart Scale:	360, 60 or 10 deg/20-in. chart cycle

R-7: Scientific-Atlanta, Model 1114A, Frequency-Tracking Servo.

Frequency Range: 50 cps to 1200 cps

(using T-8 as a frequency divider extends the upper limit to 1.2 Mc)

Output:	23TX6 synchro - linear or logarithmic
Conversion Accuracy:	1% of full scale

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5. Auxiliary Equipment

A-1: Ballantine, Model 300H, Electronic Voltmeter.

Frequency Range:	10 cps to 1 Mc
Voltage Range:	30 μV to 330 V
Accuracy:	2%, 10 cps to 700 kc 3%, 700 kc to 1 Mc
Input Impedance:	2 MΩ shunted by 15 pF

A-1A: Same as A-1

A-2: Tektronix, Model RM564, Storage Oscilloscope.

Storage Time:	Up to 1 hour
Erase Time:	0.25 sec

Type 3A1-Dual Trace Vertical Amplifier.

Frequency Range:	dc to 10 Mc
Calibrated Sensitivity:	10 mV to 10 V per division
Input Impedance:	1 MΩ shunted by 47 pF
Input Voltage:	600 V maximum

Type 3B3-Time Base Unit.

Sweep Mode:	Normal or delayed
Sweep Rate:	0.5 μsec to 1 sec/division

A-2A: Same as A-2 plus:

Type C-12 Camera with Mounting Bezel.

Film:	Polaroid Land Pack Film

A-3: Scientific-Atlanta, Model 1157-1 Absolute Value Calibrator.

Frequency Range:	50 cps to 2 Mc
Input and Output Impedance:	75Ω
Maximum Voltage Output:	0 dB V
Minimum Voltage Output:	-110 dB V
Voltage Increment:	1 dB

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A-4: Scientific-Atlanta, Model 1151, Step Attenuator.

Frequency Range:	50 cps to 2 Mc
Input and Output Impedance:	75Ω
Attenuation Range:	0 to 51 dB in 1-dB steps
Maximum Power Input:	0.25 W

A-5: Dranetz, Model 100C, Complex Impedance-Admittance Meter.

Frequency Range:	R±jX or G±jB - 100 cps to 200 kc Z-Angle or Y-Angle - 100 cps to 100 kc
Accuracy:	±2% full scale vector amplitude ±2 1/2% full scale vector phase to 150 kc ±5% full scale vector phase to 200 kc
Minimum Full Scale Impedance:	10Ω
Maximum Full Scale Admittance:	25,000 micromhos

A-6: General Radio, Model 1900-A, Wave Analyzer.

Frequency Range:	20 cps to 54 kc
Voltage Range:	30 μV to 300 V
Bandwidth:	Selectable - 3, 10, and 50 cycles

A-6A: Hewlett-Packard, Model 310A, Wave Analyzer.

Frequency Range:	1 kc to 1.5 Mc
Voltage Range:	10 μV to 100 V
Bandwidth:	200 cps - 1 kc to 1.5 Mc 1000 cps - 5 kc to 1.5 Mc 3000 cps - 10 kc to 1.5 Mc

A-7: Moseley, Model 136A, Two-Pen, X-Y Recorder.

Paper Size:	8 1/2 x 11 in.
Pen Speed:	20 in./sec, each axis

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A-8: Hewlett-Packard, Model 297A, Sweep Drive (used with A-6, A-6A and T-3).

Sweep Limits:	Any interval from 10 deg to 64 revolutions
Shaft Speed:	Selectable, 1 rpm or 10 rpm

A-8A: Same as A-8

A-9: Tektronix, Type P6015, High Voltage Probe.

Voltage Rating:	40 kV peak
Attenuation:	60 dB

A-10: Pearson, Model 110, Current Transformer.

Sensitivity:	0.1 V/A
Frequency Response:	1 cps to 35 Mc
Maximum Input:	50 A rms 5000 A peak
Rise Time:	20 nsec
Droop:	0.5%/msec

A-11: Acton Laboratories, Model 329B (with type C plug-in), Calibrated Phase Shifter.

Input Impedance:	1 MΩ shunted by 20 pF
Input Voltage Range:	0.3 to 3.0 V
Phase Shift Range:	0 to 360 deg
Accuracy:	±0.5 deg
Output Impedance:	100Ω

A-12: Scientific-Atlanta, Special Attenuator.

Linear Potentiometric Voltage Divider

Input Impedance:	1000Ω
Output Impedance:	0 to 1000Ω

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6. Option A

O-1: Moseley, Model 2DR, X-Y Recorder, with built-in Type F-3B Optical Line Follower.

Paper Size: 11 x 17 in.

Pen Speed: 20 in./sec, each axis

Line follower automatically follows any line prepared with pencil or pigment ink and regenerates original electrical data recorded previously.

O-2: Scientific-Atlanta, Model 1154, Summing Unit.

Algebraically sums two dc signals.

D. General Testing Procedures

1. Horizontal or Vertical Beam Patterns--Pulsed or CW

The entire transmitting subsystem with the exception of T-2 is used to drive either the transducer to be calibrated or a test projector. The E-I normalizer need not be switched out of the system, although it is not required for single frequency measurements. If the transducer to be driven is a multistave type to be measured in an SDT mode, the correct transmit scanner must be used to provide drive signals for 12 power amplifier modules (T-7B) that drive 12 adjacent staves. The entire receiving subsystem is used with the exception of one of the recorders. R-5 is used for patterns with major lobes of 5 deg or less; R-6 is used for other patterns. In pulsed operation, care must be taken to delay the receive gate properly to avoid both the presteady-state portion of the received pulse and any surface or bottom reflections present. The fact that the detector requires only a short pulse simplifies this greatly. Transmit pulselength and repetition rate depend, of course, upon the projector in use as well as the geometrical arrangement of transducers.

2. RDT Beam Patterns

For RDT patterns, the transducer is held fixed and the beam rotates as the transmit scanner rotates. An individual power amplifier must be provided for each of at least 20 staves of the 48 stave transducers in order to measure a 60-deg pattern. The transmit scanner receives a continuous single-frequency signal from T-3. As it rotates, the beam sweeps through a 60-deg sector centered on the 20 adjacent staves. The hydrophone should be placed at the center bearing. The entire receive subsystem is used in the CW mode except for R-6. R-5 must be used to plot the RDT pattern because of its higher pen response. The chart is driven internally at constant speed for these measurements.

3. Sensitivities vs Frequency--Pulsed or CW

The entire transmit subsystem is used except T-2. T-5 is used to maintain constant current or voltage drive to the projector. The hydrophone output goes to the entire receive subsystem except for R-6. The chart drive for R-5 comes from R-7. For hydrophone calibration, the response of both the unknown hydrophone and a calibrated hydrophone are plotted on the same chart and compared. For projector calibration, ideally a calibrated hydrophone with a flat response is used to plot a response vs frequency on R-5. A known voltage, applied to the receive subsystem input, is used to establish a reference point on the chart for absolute calibration. If the standard hydrophone does not have a flat response, its response must also be plotted and taken into account.

The additional equipment constituting Option A permits the natural response of a hydrophone or projector to be "flattened" electronically. This permits absolute responses to be plotted without data reduction.

4. Low-Level Complex Impedance or Admittance vs Frequency--CW Transmission

These measurements can be made by the use of the complex impedance-admittance meter (A-5). The components can be plotted vs frequency on the recorder A-7 by using either of the wave analyzers (A-6 and A-6A) as signal sources. The drive unit A-8 sweeps frequency and provides the X input to A-7. If higher power drive is required, the power amplifier T-7 can be used.

5. High-Level Complex Impedance or Admittance--Pulsed or CW

The high level impedance subsystem is used to measure drive voltage amplitude, drive current amplitude, and the phase shift between the two waveforms. Impedance or admittance can then be computed from these parameters. Two schemes of measurement can be used with this subsystem; both give only point-by-point measurements. The voltage and current probes and the two filters (R-2A and R-2B) provide signals A and B, respectively, to the oscilloscope (A-2A). The signals are the fundamental voltage and current components. In technique I, units A-11, A-12, and A-1A provide a coherent reference signal, variable in amplitude and phase. This signal C is added to A or B (within the oscilloscope amplifier) and is adjusted to cancel A or B. As A and B are sequentially cancelled, amplitude and phase of C are noted and used to compute easily the desired parameters.

Technique II is oriented toward more rapid measurement of a series of impedances of roughly the same magnitude, for example, a series of element impedances of a multielement transducer. In this technique the voltage and current waveforms (A and B) are displayed simultaneously on the dual-trace oscilloscope and photographed. The amplitudes and the phase shift are measured from the photograph.

Technique I is the more accurate of the two, involves little data reduction, but necessitates many pulses in order to achieve the nulls.

Technique II, slightly less accurate, does involve data reduction from photographs, but has the great advantage of speed on transducers that are duty-cycle limited. In a series of impedance measurements, only one pulse is needed per measurement.

6. Harmonic Distortion--Pulsed or CW

Harmonic distortion in the acoustic output of a transducer can be measured by the use of one of the wave analyzers (A-6 and A-6A) and the oscilloscope (A-2). The oscilloscope is used to measure the signal amplitudes in pulse measurements. The analyzer meter indication is adequate for CW measurements. The transmitting subsystem (excluding T-2) is used to drive the transducer under test at the correct power level.

7. Shipyard Tests from "Performance Standards Book for Sonar Transducers"

Many of these tests have been covered by the five previous categories. Many others are very simple tests involving the use of such instruments as an electronic volt-ohm-milliammeter and a megohmmeter. Although these devices are necessary and should also be standardized at the shipyards, they are deemed portable items and are not components of the system. Item T-2 of the transmitting subsystem is included to satisfy the requirement of a noise source for one of the tests prescribed for the AN/BQR-2B (DT-168) transducers. This particular test is a simple response measurement with T-2 used in place of the signal generator T-3. The noise generator also provides the capability to use the hydrophone calibration technique presently employed in one of the test tanks at San Francisco Bay Naval Shipyard. In this technique the hydrophone is placed in a continuous uniform noise field in a tank, and its response is plotted vs frequency by the use of a tracking filter. This type of response can be plotted as outlined in Section 3, except that T-2 is used instead of T-3 as a signal source, and that the receiving subsystem is replaced by one of the wave analyzers. The analyzer, swept through the frequency band of interest by A-8, is used as a tracking filter. The analyzer output can easily be plotted vs frequency on either the rectangular recorder (R-5) or on the X-Y recorder (A-7).

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IV. SUMMARY AND RECOMMENDATIONS

A. Summary

The seven capabilities presented in section III.A were agreed upon as reasonable for shipyard transducer repair facilities. Only the measurement of RDT beam patterns was questioned and was reduced to an optional status.

With the exception of the measurement of complex impedance and of harmonic distortion, the system described herein is fully adequate for farfield acoustic measurements. Compatibility with nearfield techniques has been maintained. The recommended complex impedance instrumentation is somewhat makeshift; it can be improved as development progresses on instruments for more automatic, direct measurement of pulsed high-power impedance. As more is learned about the utility of harmonic distortion measurements, it may be desirable to supplement the system with instruments more suitable for simple, fast checking than wave analyzers.

The final system design herein departs slightly from that agreed upon at the BuShips meeting of 27 October. The question of high-level impedance measurement capability--left open at the meeting--was answered by the high-level impedance subsystem. This involved the addition of two variable bandpass filters, an oscilloscope, a calibrated phase shifter, an attenuator, and ac voltmeter. In the light of the consensus favoring elementwise and stavewise transducer checking at the shipyards, the firm power amplifier specification was changed to 24 kVA, which is adequate with a reasonable margin. Two options are specified that provide the capability for RDT or SDT measurements on four present fleet transducers. Several minor changes in the system were made, such as: (a) a different brand of equivalent variable bandpass filters was specified; (b) an additional electronic counter, included only for frequency monitoring purposes, was found to be unnecessary; (c) the model numbers of the Scientific-Atlanta recording system were corrected; (d) the dc volt-ohm-milliammeter and the megohmmeter were omitted as system components due to the desirability of their remaining portable items; and (e) the rotator position indicator and synchro reference were regrouped with rotators and controls as items that necessarily should be custom engineered for each transducer repair facility.

Appendix A contains a list of the system component prices. It should be noted that an assembled system would cost more than the sum of the component prices.

B. Recommendations

1. It is recommended that at least four units of the herein specified calibration system (including option A) be purchased for the shipyard transducer repair facilities as soon as funds are available. The system should be engineered so that all items are console mounted with appropriate internal cabling, impedance matching, and instrument cooling.

2. It is recommended that the question of the shipyards' requirement for RDT or SDT testing capability be resolved as soon as possible in order that the 8 power amplifier modules as herein specified may be supplemented as is necessary.

3. It is recommended that the system be mounted in three separate consoles--console I for the 24 kVA power amplifier, console II for the high-level impedance subsystem, and console III for the remainder of the system. Consoles II and III should be mounted on casters for portability and should be arranged in such a way that other instruments might be added to them at some later time.

4. In the event sufficient funds are not immediately available for the entire system to be purchased for the shipyard facilities, and in the event it is deemed necessary immediately to provide some instrumentation to the facilities, it is recommended that any instruments provided be components or subsystems of the recommended system so that at some later time these instruments may be integrated into the complete system.

5. It is recommended that at such time as instruments are developed for more direct, faster measurement of both high-level impedance and harmonic distortion with pulsed transmission, their addition to the calibration system be considered.

6. It is recommended, concurrent with the system procurement, that the overall improvement and standardization program for the transducer repair facilities continue. Water conditions at each facility should be investigated and improved as necessary to achieve standard test distances and test depths. Additional specific requirements must be met in order to complement the new system. Due to the differences between facilities and the nature of these requirements, they could not be specified as parts of the system, but must be custom engineered for each transducer repair facility. These include adequate space in which to house the system, adequate cabling between the consoles and test shafts, and adequate transducer handling and rotating capability. Console I should be permanently mounted remote from console III of the system and will require strong support due to its weight. Console III should be portable so that it can remain near the test shaft in use. Console II should be portable in order that it can be used adjacent either to console I or to console III. The cabling requirements, of course, depend on the layout of the three consoles at a particular facility. Rotators (including controls, compatible synchro position outputs, synchro position indicators, etc.) and shafts should be provided to each facility in sufficient numbers and of sufficient capacities. Certain standardized portable auxiliary instruments should be provided in sufficient numbers--such as volt-ohm-milliammeters and megohmmeters. A temperature profile recorder should be provided to augment each calibration system. This was not included in the system because the array of temperature probes must be engineered for a particular water depth.

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7. It is recommended that work begin immediately on the establishment of standardized testing and calibration procedures for the transducer repair facilities. Procedures should be included for testing each type of transducer encountered at the facilities. For large ASW transducers, emphasis should be placed on element or stave checking. Nearfield techniques should be considered where they are feasible.

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Appendix A

Approximate Component Price List

T-1	Pulse-Timing Generator	$ 1,800
T-2	Noise Generator	130
T-3	Signal Generator	615
T-4	Transmitter Gate	440
T-5	E-I Normalizer	4,500
T-6	Driver Amplifier	162
T-7, 7A	Power Amplifier (2 required)	1,370
T-7B	Power Amplifier	33,760
T-8	Electronic Counter	1,550
R-1	Differential Preamplifier	1,800
R-1A	Voltage Amplifier	600
R-2, 2A, 2B	Variable Bandpass Filter (3 required)	1,500
R-3	Line Driver	250
R-4	Receiver Gate	470
R-5, 6	Recording System	10,575
R-7	Frequency Tracking Servo	4,400
A-1, 1A	ac Electronic Voltmeter (2 required)	510
A-2, 2A	Storage Oscilloscope (2 required)	4,595
A-3	Calibrator	1,500
A-4	Step Attenuator	150

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A-5	Complex Impedance-Admittance Meter	$ 3,450
A-6	Wave Analyzer	2,150
A-6A	Wave Analyzer	2,000
A-7	X-Y Recorder	2,650
A-8, 8A	Mechanical Sweep Drive (2 required)	750
A-9	Voltage Probe	200
A-10	Current Probe	235
A-11	Phase Shifter	1,295
A-12	Attenuator	250
	TOTAL	$83,657

Option A

0-1	X-Y Recorder with Optical Line Follower	3,095
0-2	Summing Unit	250
	TOTAL	$ 3,345

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Appendix B

Conference Report [Encl. (1) not included]

Subj: Naval Shipyard Transducer Repair Facilities; Instrumentation for

Date: 27 October 1965

Time: 0900 - 1230

Place: Room 2433, Main Navy Building, Bureau of Ships

Persons Attending:

Mr. Glenn C. Moore	Bureau of Ships - Code 1622
Mr. Frank Andress	Bureau of Ships - Code 1624
Mr. Dudley Baker	Defense Research Laboratory
Mr. O. M. Craven	Bureau of Ships - Code 627J
Mr. Charles Eversole	Bureau of Ships - Code 1624/TRACOR
Mr. Charles Green	Navy Electronics Laboratory
Mr. J. Larson	Naval Research Laboratory
Mr. Eugene Spurlock	Stanford Research Institute
Mr. James Stockton	Defense Research Laboratory
Mr. W. James Trott	Underwater Sound Reference Laboratory
Mr. James Whitely (sic)	Bureau of Ships - Code 1622/DRL
Mr. Hugo Wilms, Jr.	Underwater Sound Laboratory

Ref: (a) DRL-A-238 "The Transducer Calibration Requirements and Capabilities of the Bureau of Ships--Present and Future" by D. D. Baker, G. R. Barnard, and J. E. Stockton dtd 15 Feb 65

(b) "Design of an Optimum Standardized Transducer Calibration Facility" First Draft by D. D. Baker and J. E. Stockton dtd 24 May 65

Encl: (1) BUSHIPS Memo Ser 1624-467 dtd 18 Oct 65

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Purpose

The purpose of this meeting was to review reference (b) and subsequent comments thereto and to generate a "master list" of instrumentation required by the Naval Shipyard Transducer Repair Facilities for the calibration of sonar transducers. This instrumentation is to be in the form of a complete and usable system.

Background

The Naval Shipyard Repair Facilities, Boston, Mare Island, and Pearl Harbor Shipyards, are charged with the responsibility of repairing sonar transducers used in the Fleet. After a transducer has been repaired, it must be tested to insure that it is functioning properly before being installed aboard ship. Reference (a) revealed that the instrumentation required to perform these tests is antiquated, unreliable, and badly in need of replacement. Enclosure (1) confirmed that this situation still exists at Boston and there is no reason to believe that the situation has improved at the other repair facilities. At the request of BUSHIPS, DRL prepared the design of reference (b). Hence, this meeting was called to review the recommendations of reference (b) and prepare a final list of instrumentation from which a system could be designed suitable for calibration of transducers at the repair facilities.

Brief

Several subjects relative to the instrumentation required by the Naval Shipyard Transducer Repair Facilities were discussed. Included in these topics were the desirability of standardization between shipyards, the use of bench tests, the need for Rotational Directional Transmission (RDT) measurements on complete units, in-situ tests, package system versus discrete elements to be integrated into present system, availability of funds, procedures, and a discussion of each unit recommended by DRL.

As a result of these discussions, a "master list" of instrumentation was generated. DRL agreed to compile this list and issue a final report. BUSHIPS will investigate the availability of funds.

Action Required

The Bureau of Ships is required to:

(a) Explore all possible sources of funds for money to purchase the specified calibration system.

(b) DRL will complete final report based on the findings of this meeting.

Detailed Discussion

A conference to discuss instrumentation for Shipyard Transducer Repair Facilities was convened at the Bureau of Ships on 27 October 1965 by the Chairman, Mr. Glenn C. Moore. Mr. Moore began by stating the purpose of the meeting. He explained that the shipyards are required to calibrate transducers they have repaired to insure that specifications are met. They are handicapped by lack of adequate testing techniques, procedures, and instrumentation. Because of the existing conditions, standardization is hopeless. For this reason, BUSHIPS Code 1622D chose to specify a standard calibration system to be used by each shipyard facility. Using the report of reference (b) as a basis for discussion, Mr. Moore expressed the hope that the attendees could come to an agreement on a "master list" of equipment that could be used as a basis for the purchase of any instrumentation for the shipyard calibration facilities. He further explained that once a standard system has been installed at each activity, it is then practicable to specify a standard set of procedures for each transducer type.

Mr. Moore then asked for discussion regarding the desirability of standardization between shipyards. Mr. Andress felt standardization was very desirable in order that results between laboratory and shipyards and of sonar transducers, he has been assigned this task. His findings to date indicate that the transducer repair facilities have no quality assurance program comparable to the submarine antenna group. One notable example given was in the inspection of cables prior to shipboard installation. The Submarine Antenna Quality Assurance Facility inspects all cables prior to installation. No such program exists for transducers; in fact, Boston and the Electronic Maintenance Engineering Center (EMEC) say that cables are often undersized or oversized resulting in degraded performance and premature failure. Negotiations are presently underway to arrange for SAQAF to inspect cables used for sonar transducer installation. From his recent visit to Boston, Mr. Andress discovered that Boston felt they could live with the rest of their test equipment if a Scientific-Atlanta Polar Recorder and auxiliary equipment were provided. Although he felt a "turn key" system for each facility would be desirable, he cautioned that availability of funds would have to be investigated. Mr. Moore felt that if a set of instrumentation could be agreed upon, this was a good time to explore means for obtaining funds. Mr. Green pointed out that many problems would be encountered if individual items were integrated into the existing test systems, probably making it more economical in the long run to provide a complete system.

Mr. Moore suggested that each individual unit recommended by DRL be reviewed at this time. Mr. Baker explained that the system as originally specified was not directed specifically toward shipyards and some recommended tests such as reciprocity might not be applicable. In answer to a question by Mr. Moore, Mr. Green and Mr. Baker agreed that the system as specified was basically a Scientific-Atlanta system.

Mr. Baker explained that item T-10, the Scientific-Atlanta Model 1140 Complex Impedance Recorder is not available since Scientific-Atlanta has not completed development. Mr. Trott revealed that USRL demonstrated a similar device at the last WESCON show. Mr. Larson stated that Raytheon has also built a complex impedance measuring device with a digital display. For CW measurements, Mr. Green and Mr. Wilms agreed that the Dranetz equipment performed well except for a slight degradation in accuracy at high phase angles. In response to a question by Mr. Craven, the availability and desirability of a calibrator to periodically check the measurement system was confirmed. Mr. Wilms pointed out that no patching should be necessary to use the calibrator. Mr. Wilms provided the information that Raytheon's complex impedance device had a 20 dB dynamic range for any one adjustment. By readjusting, another 20 dB can be covered and in this manner a wide range can be utilized. Mr. Trott was not certain but thought that the USRL unit had a 50 or 60 dB dynamic range.

Mr. Spurlock inquired if the system was limited to one operation at a time. Mr. Baker explained that basically this was true, but that by use of two rotators, light and heavy, the console can be kept in operation near 100 per cent of the time. Examination of the overall system specifications revealed the need to shift the signal gate duration up one decade, i.e. to cover the range 100 micro-seconds to 10 seconds.

Proceeding with the overall system specifications review, the 20 modular 3 kVA power amplifiers were discussed. Mr. Baker explained that 60 kVA gave the capability to measure RDT beam patterns over a 60° sector for SQS-4 and smaller ASW transducers. He further explained that 3 kVA modules were chosen because this is the power required to drive one stave of the SQS-4 transducer.

Mr. Green and Mr. Wilms questioned the need for RDT measurements at the shipyards. Mr. Wilms pointed out that if an RDT measurement at the shipyard indicates satisfactory performance and unsatisfactory results are observed after shipboard installation, this only tells one that the electronics are malfunctioning.

The discussion then proceeded to the remaining measurement capabilities specified by DRL. The real-time plotting of sensitivities vs frequency--pulsed or CW was deemed a desirable test and within the capability of the specified equipment. The real-time plotting of complex impedance or admittance--pulsed or CW was thought desirable, but the instrumentation required for the pulsed mode is not commercially available. Mr. Wilms indicated that USL is conducting further investigation(s) of the total harmonic distortion measurements patterned after the early work of Bishop and Wilson. Mr. Trott felt that this measurement could be modified for use in air and recommended that USL develop procedures and specify tolerances for its use.

The last item specified under measurement capabilities, all tests currently performed at Naval Shipyards, was also discussed briefly. Mr. Baker explained that this was included to insure that none of the present shipyard capabilities are lost. Mr. Moore explained that after standard instrumentation has been obtained, procedures will be developed and a new manual issued to replace the Performance Standards Book For Sonar Transducers.

Each individual component recommended by DRL was then discussed. Agreement was obtained on the best instrument for each unit. These choices will be itemized in the final DRL report. Relative to the rotators required, the attendees agreed that the individual requirements and existing rotators be reviewed before specifying a particular unit.

The system as specified is composed of the following instruments:

T-1: Scientific-Atlanta, Model 1118B, Pulse Timing Generator.
T-2: Grason-Stadler, Model 455B, Noise Generator.
T-3: Hewlett-Packard, Model 651-A, Oscillator
T-4: Scientific-Atlanta, Model 1111, Transmitter Signal Gate.
T-5: Scientific-Atlanta, Model 1153, Voltage-Current Normalizer.
T-6: General Radio, Model 1206-B, Unit Amplifier.
T-7: Krohn-Hite, Model DCA-50, Power Amplifier.
T-7A: CML, Model A3K, Power Amplifier.
T-8: Hewlett-Packard, Model 5532A, Electronic Counter.
T-9: Scientific-Atlanta, Model 114A, Frequency-Tracking Servo.
T-10: Hewlett-Packard, Model 521G, Electronic Counter.

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R-1: Scientific-Atlanta, Model 1116, Wideband Differential Preamplifier.

R-2: SKL, Model 302, Variable Electronic Filter.

R-3: Scientific-Atlanta, Model 1121, Line Driver.

R-4: Scientific-Atlanta, Model 1112, Receiver Signal Gate.

R-5: Scientific-Atlanta, Series 1160, Plug-In Detector Unit.

R-6: Scientific-Atlanta, Model 1523, Rectangular-Coordinate Recorder.

R-7: Scientific-Atlanta, Model 1530 P-S136, Polar-Coordinate Recorder.

A-1: Ballantine, Model 300H, Electronic Voltmeter.

A-2: Tektronix, Model RM564, Storage Oscilloscope.

A-3: Scientific-Atlanta, Model 1151, Precision Decade Attenuator.

A-4: Scientific-Atlanta, Model 4401, Position Indicator Unit.

A-5: Model 4570, Adjustable Synchro Reference.

A-6: Dranetz, Model 100C, Complex Impedance-Admittance Meter.

A-7: General Radio, Model 1900-A, Wave Analyzer.

A-8: Hewlett-Packard, Model 310A, Wave Analyzer.

A-9: General Radio, Model 1862-C, Megohmmeter.

A-10: Hewlett-Packard, Model 412A, dc Volt-Ohm-Milliammeter.

A-11: Moseley, Model 136A, Two-Pen, X-Y Recorder.

A-12: Hewlett-Packard, Model 297A, Sweep Drive (used with A-8, A-8A and T-3).

A-13: Scientific-Atlanta, Model 1115, Calibrator.

A-14: Pearson, Model 110, Current Transformer.

A-15: Small and Large Rotators with Rotator Controls-Will be tailored to individual requirements at each shipyard.

O-1: Moseley, Model 2DR, X-Y Recorder, with built-in Type F-3B Optical Line Follower.

O-2: Scientific-Atlanta, Model 1154, Summing Unit.

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